THE 4-MeV SEPARATED-ORBIT CYCLOTRON*

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Summary

The Separated-Orbit Cyclotron Experiment (SOCE)[1] will extend and complement earlier theoretical and experimental studies and will provide a unique facility for the evaluation of an operating SOC system. The six-sector, four-turn accelerator will provide maximum energies of 4 MeV for protons and deuterons and 8 MeV for $^3He^{++}$ and $^4He^{++}$ ions. The output energy is variable over a 2:1 range by adjustment of the magnetic field and acceleration of the ions at the appropriate harmonic of the ion frequency. Ions are injected into the SOC at one quarter the final energy. The injection system consists of a duoplasmatron ion source, a 500-kV dc accelerator, and a three-cavity linear accelerator. Proton currents in the 10- to 20-mA range are predicted. The principal characteristics of the accelerator are given in Table I.

All of the major components have been fabricated and delivered on site except the injector's linac cavities, which are expected shortly. The photograph in Fig. 1 shows the accelerator as seen from the control area on a mezzanine about 40 feet away. The SOC sector magnets and rf cavities are in the approximate location, with the dc injector components in the background. The tops of the magnet yokes have been temporarily removed to permit completion of pole tip alignment. An rf power amplifier will be mounted on the outer wall of each cavity. One of the PA units can be seen in the background (Fig. 1) on a test stand with a water-cooled dummy load. A simplified plan view of the installation is shown in Fig. 2.

The Injector

The dc section of the injector is a four-stage cascade rectifier system which will operate at a nominal output level of 500 kV. The number of stages was limited by the available overhead clearance in the machine area. The power supply has been tested at rated voltage; it appears to be capable of running somewhat higher without excessive corona. The duoplasmatron ion source will be located inside the high voltage terminal with the vertical accelerating column just below.

An injector linac consisting of three rf cavities,[2] see Fig. 3, provides an additional 500 kV of acceleration potential. Two additional cavities preceding and following the linac are to be used as bunchers. The linac is preceded by a 90° bending magnet and followed by a pair of 90° bending magnets for steering the beam into the first SOC cavity.

Control System

The entire control system including all dc power supplies with the exception of the main field excitation motor-generator set are located on the mezzanine about 40 feet from the machine perimeter. This area is sufficiently remote from the machine to be free of stray magnetic field and radiation. Of course, shielding could be added to the machine periphery if necessary. During initial operation with low-level beams where extensive fine tuning will be necessary, it will be possible to view phosphor probes in the beam lines from the control area with a telescope. Wiring between the control area and the machine is carried in open cable trays along the walls of the building. Control system wiring is complete with exception of some of the patch cabling which connects individual machine components to the machine area terminal boxes.

The main control panel, Fig. 4, is built into a row of instrument cabinets. The first unit from the left contains a General Radio frequency synthesiser which provides the main rf 50 MHz reference signal, the dc injector controls, the main magnetic field level controls, and the ion source controls. The second and third cabinets contain rf level and phase controls for each PA and cavity, and magnetic field trim-coil controls for each of the 23 pairs of SOC pole tips.

The second row of instrument cabinets located directly opposite the first row, Fig. 5, contains the rf system start-up controls, vacuum system instrumentation and controls, the trim-coil power supplies, and other miscellaneous small dc power supplies. Control system relays are located within the instrument cabinets. The several large high-voltage power supplies that are part of the rf system are located adjacent to the main control area.

Vacuum System

The vacuum system features several high-vacuum sections backed by a common forepressure system. The high-vacuum components are arranged so that each section of the accelerator; i.e., the SOC, the linac, and the dc injector, can be pumped independently. Oil diffusion pumps equipped with liquid nitrogen baffles and air-operated valves are used throughout. Each SOC cavity has a 10-in. diffusion pump, and each linac cavity and the dc accelerating column has a 6-in.

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Table I - General Characteristics of the SOCE
(for 4-MeV Protons)

Beam orbit, turns	4
Magnet sectors	6
Accelerating cavities	6
Radio frequency, MHz	50
Harmonic No.	32
Injection energy, MeV	1.0
Injection radius, cm	138
Extraction radius, cm	262
Pole-tip radius, cm	43.8
Magnetic field, kG	
Minimum	3.5
Maximum	6.5
Beam aperture, cm	3.8 x 7.6
Magnetic field index, n	0.56
Radial focusing frequency, ν_r	1.3 - 1.9
Axial focusing frequency, ν_z	1.6 - 2.4
Momentum compaction factor	1.2 - 1.7
Minimum turn spacing, cm	25
Coaxial cavities	
Drift length, $\beta\lambda$	$\sim$0.18
Gap length, $\beta\lambda$	$\sim$0.20
Peak voltage, kV	83.4
Rf power (no beam), kW	$\sim$30

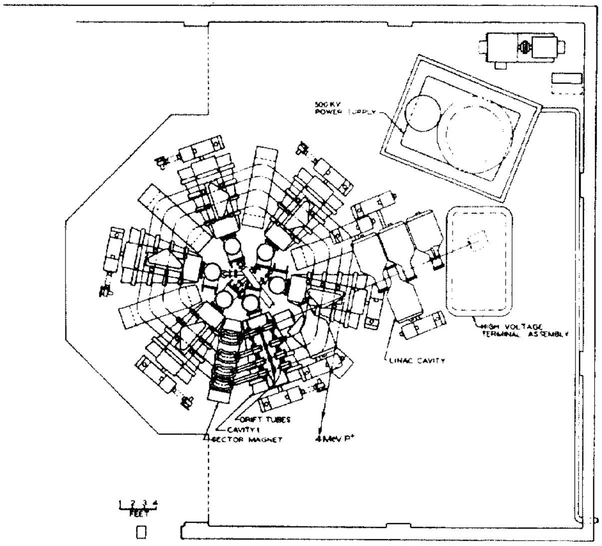

Fig. 2. Plan view of the SOCE.

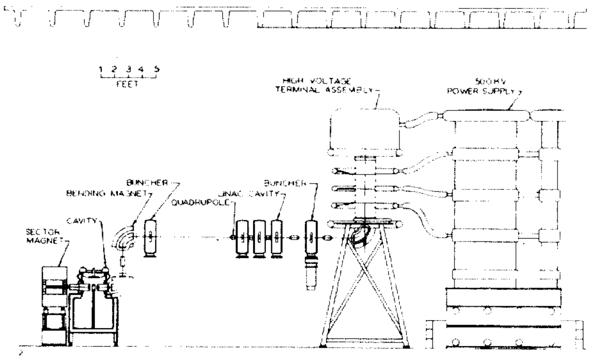

Fig. 3. Vertical schematic of the SOCE.

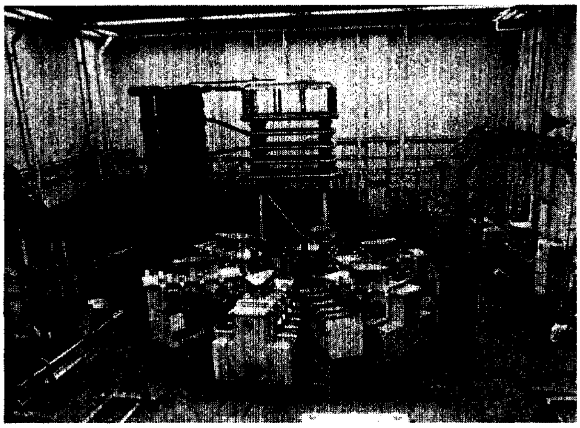

Fig. 1. The SOCE as seen from a mezzanine about 40 feet away. Equipment in foreground is unrelated. The SOC ring is in the center, the injector dc components in left background, and one PA unit is on a test stand in right background.

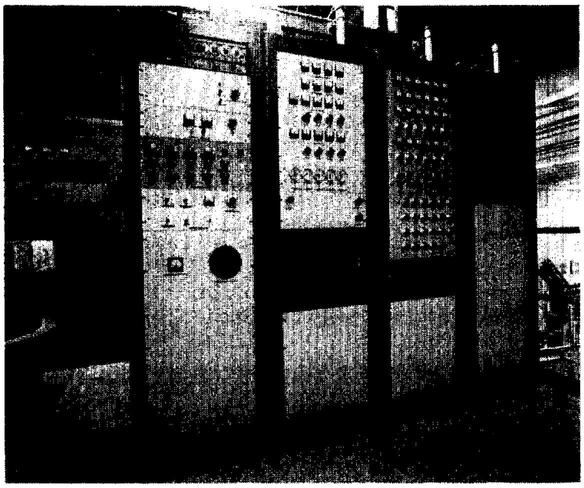

Fig. 4. The main control panel on the mezzanine overlooking the SOCE.

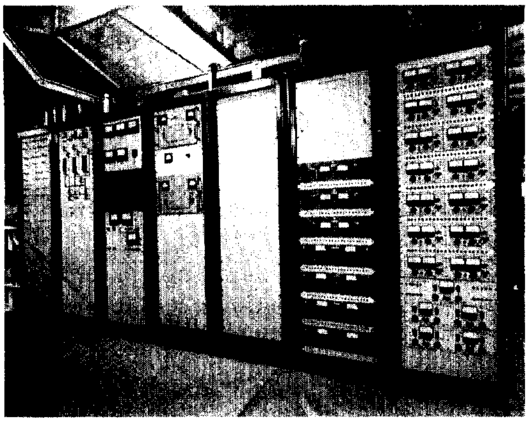

Fig. 5. The Auxiliary Control Panel just opposite the main control panel. The rf system start-up controls are on the first cabinet from the left. The vacuum system controls are on the second cabinet. The third cabinet contains vacuum system instrumentation. The remaining cabinets contain dc power supplies for the rf system and for the magnetic field trim coils.

pump. The forepressure section uses a 1000-cfm oil-sealed mechanical pump. Pressure of 1 x 10^{-6} torr is expected in the SOC beam lines. Somewhat higher pressure is expected in the accelerating column due to the ion source gas load.

Rf System

The rf cavities in the SOC and injector linac are described elsewhere.[2] Each cavity will be driven by an individual rf power amplifier, except the two buncher cavity which will share a single amplifier.

Each PA[3] has a 4CW25,000A output stage and two driver stages and will generate up to 25 kW of CW rf power at 50 MHz. The PA's will typically operate at about 10-kW output, but the maximum output will be required for high-current ion beam experiments.

One of the PA's has been operating on a test stand with a dummy load. At the 10-kW level, the PA's can operate satisfactorily without automatic tuning; however, the tuning servos will probably be necessary when the PA's are driving resonant loads.

The rf-signal-distribution circuitry is located in the main control panel, and a drive signal cable runs to each respective PA. The principle distribution components are: a 10-way power divider, phase-regulator amplifiers, phase shifters, and a 10-db booster amplifier in each PA drive line to compensate for signal attenuation. The power divider is driven by the frequency synthesizer. Each phase shifter has a ± 90° operating range. The error signals are derived by comparing a signal from each cavity with the respective power-divider output signals in a phase detector.

Magnetic Field

Five of the six sector magnets assemblies each has an H-type yoke with four pairs of pole tips. The sixth sector, which is located next to the last 90° injector magnet, has a C-type yoke and only 3 pole pairs. Each pole tip as a main excitation winding and a trim-coil winding that contributes about ± 10 percent of the total excitation. All 23 of the main windings are connected in series and driven by a motor-generator set. Each trim-coil is wired to a patch panel in the control area where it is connected to the appropriate one of 23 assorted power supplies ranging in size from 0-3 amps to 0-25 amps. These trim coil power supplies operate at just a few volts potential.

Magnetic field measurements were taken from one sector magnet and extrapolated to the other sectors. The trim-coils on each pole tip will be adjusted for final field corrections.

Machine Alignment

Pole tip alignment is one of the more critical parameters on SOC-type accelerators. The SOCE tolerances are particularly representative of the tightest to be expected on higher energy machines. The tolerances on each pole tip are:

Radial displacement	± 0.025 in.
Azimuthal displacement	± 0.025 in.
Skew	± 1.2 deg.

Each pole is at a different radius and set at a different angle. The radially symmetrical poles are not located symmetrically on the sector magnet; rather they are rotated in the median plane, each a specific amount to give the ion beam its required radially outward components. The pole tips are aligned by means of a jig plate manufactured to close tolerances on a numerically controlled machine tool. Dowel holes in the pole tips are brought into coincidence with corresponding holes in the jig plate to provide alignment of pole tips in a given sector with respect to each other. A common datum hole in the jig plate provides means for radial positioning of the pole tip group in each sector within ± 0.001 in. with respect to the center of the machine. Optical tooling is used to bring the magnetic median plane of each pole tip within ± 0.001 in. of an arbitrarily established machine median plane.

Conclusion

The work remaining to complete the SOCE is largely in the category of alignment, installation, and testing. If no unforeseen delays develop, it seems certain that the first beam can be obtained in mid-1969.

References

1. R. E. Worsham, E. D. Hudson, R. S. Livingston, J. E. Mann, J. A. Martin, S. W. Mosko, and N. F. Ziegler, "A 4-MeV Experimental Separated-Orbit Cyclotron," IEEE Trans. on Nuclear Science, NS-14, No. 3, 760 (June 1967).

2. N. F. Ziegler, "Test Results from Coaxial Cavities for Separated-Orbit Cyclotrons," published in these proceedings.

3. S. W. Mosko, "The Separated-Orbit Cyclotron Experiment Rf Power System," IEEE Trans. on Nuclear Science, NS-14, No. 3, 246 (June 1967).